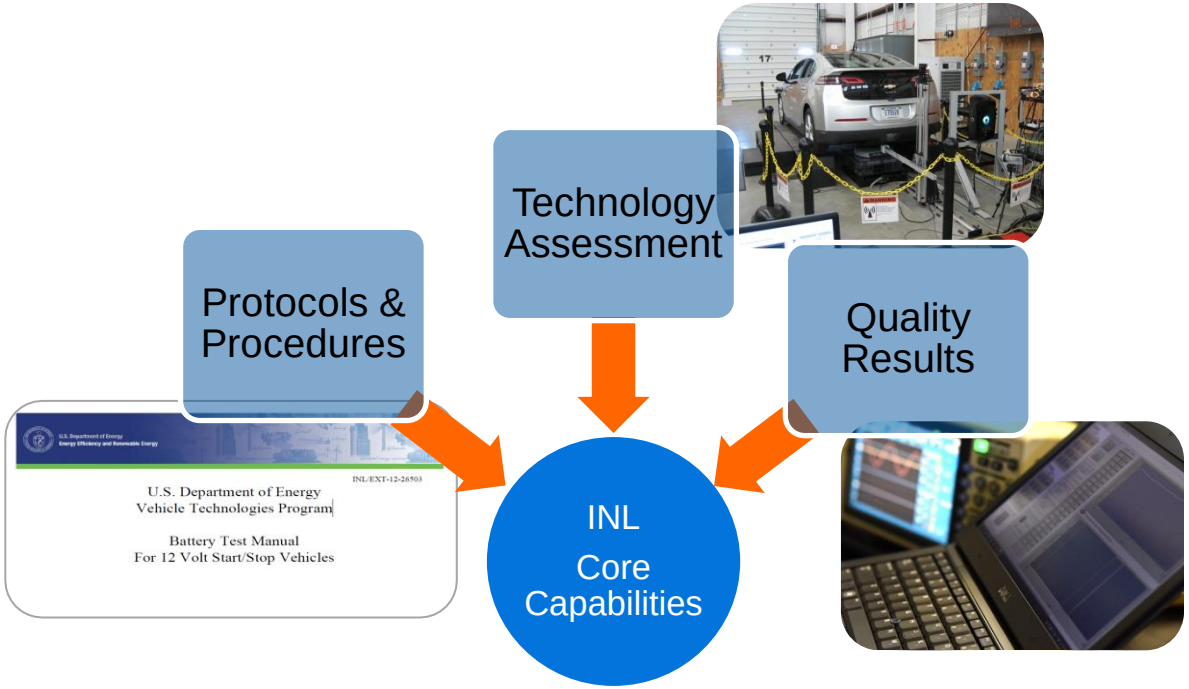
Electric Vehicle Infrastructure (EVI) Lab: Wireless and Conductive Charging Testing

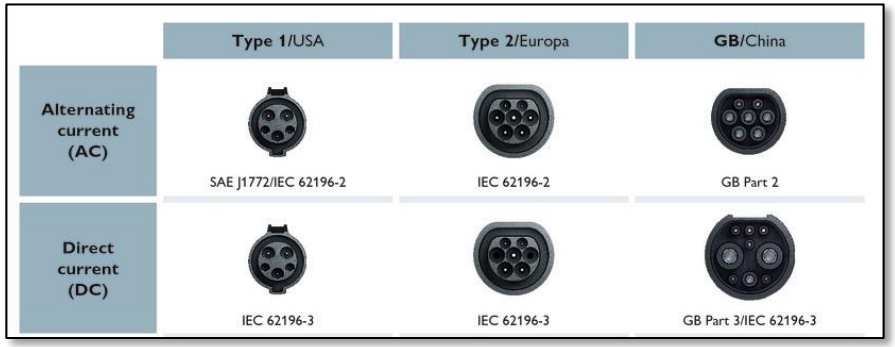


Shawn Salisbury

INL Tech-to-Market (T2M) Workshop *May 19-20, 2015*

Why have the Electric Vehicle Infrastructure (EVI) Laboratory?

- Non-unified standards limit consumer acceptance and marketplace penetration
  - Support codes and standards development
- Electric vehicle charging needs to be well understood as electric grid becomes more modern
  - Provide independent testing of plug-in electric vehicle (PEV) charging systems
  - Evaluate cyber security of charging systems



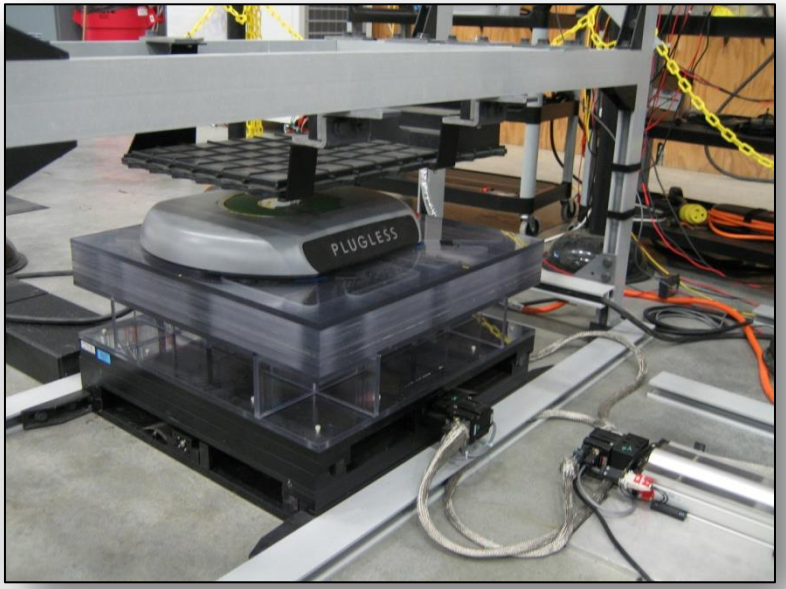
Testing focus & facility capabilities

- Evaluate performance of conductive and wireless charging systems
- Wide range of input power
- Vehicle emulator (for bench tests)
- Chevy Volt and Nissan Leafs

Wireless Charging: Evaluation and Test Procedure Development

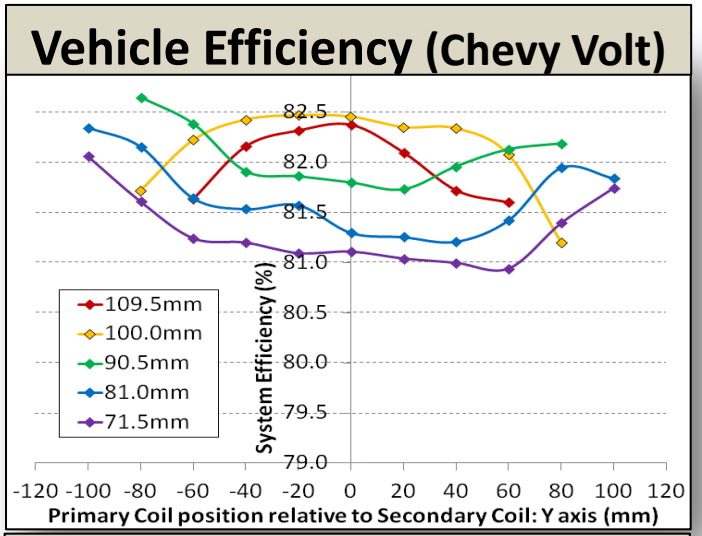
Wireless charging testing and evaluation

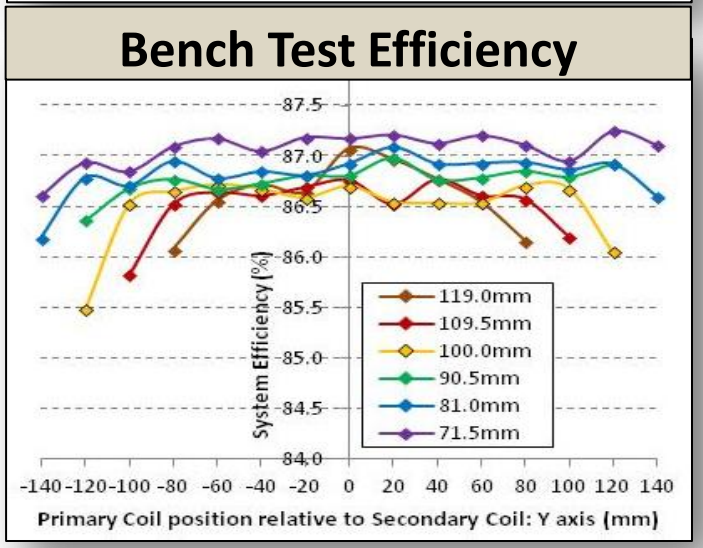
- On-board vehicle testing
- Standalone sub-system testing (bench test)
- Directly supports SAE J2954 test procedure development



Test results: PLUGLESS system efficiency

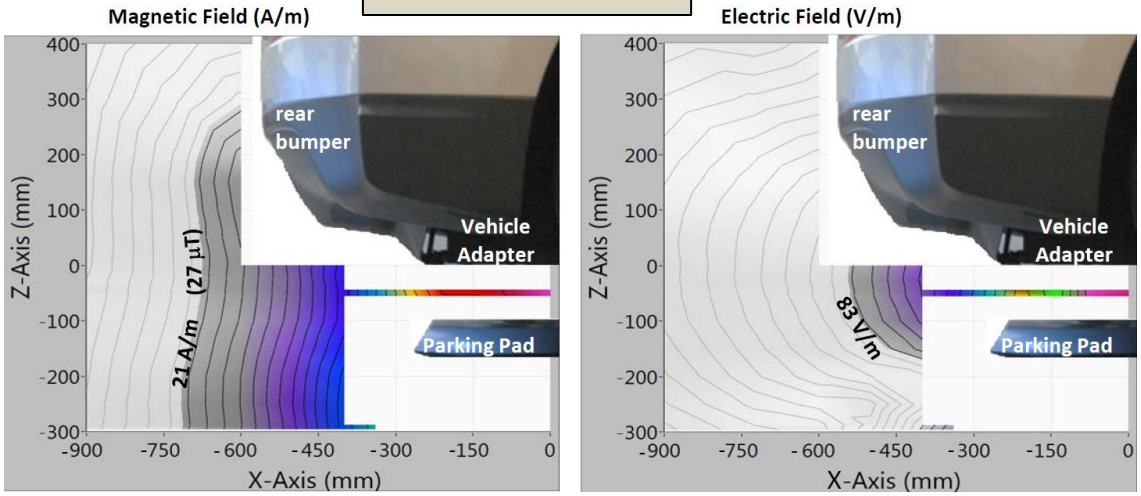
- Efficiency varies with coil gap and misalignment
- Significant differences between on-board and bench testing
  - Due to steel vehicle chassis absorbing electromagnetic field
- Output power also has efficiency effects
  - Decreased power → decreased efficiency



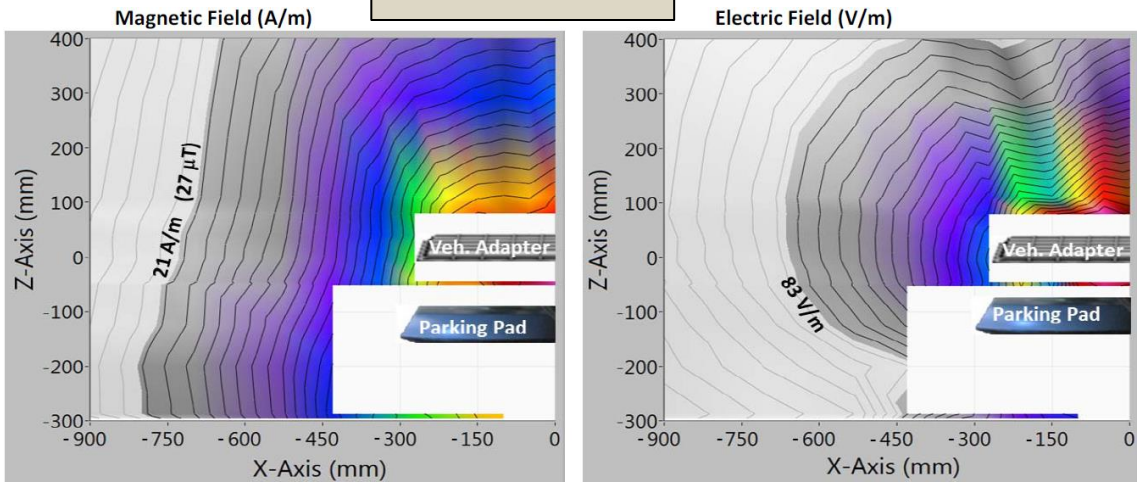


Test results: EM-field measurements

On Vehicle



Bench Test



Fact Sheet: vehicle test results

Advanced Vehicle Testing Activity — Idaho National Laboratory

PLUGLESS™ Level 2 EV Charging System (3.3 kW) by Evatran Group Inc.

Results from Laboratory Testing as installed on a 2012 Chevy Volt

Description / Specifications [1]

System Input Voltage operating Voltage	208 to 240	VAC
Circuit Breaker Rating	30	A
Nominal gap between coils	100	mm
Rated maximum power output	3300	watts
Parking Pad (Primary Coil system)		
Shape	Approximately Circular	
Size	559 dia. x 470 long	mm
Vehicle Adapter (Secondary Coil system)		
Shape	Rectangular	
Size	762 long x 457 wide	mm

Measured System Parameters during nominal, steady state conditions [2]

Input Power		
Input Voltage	208	VAC
Input Current RMS	28	Amps RMS
Power Factor	0.60	
Voltage Total Harmonic Distortion (THD)	3	%
Current Total Harmonic Distortion (THD)	134	%
Wireless Power Transfer Operation		
Operating Frequency (kHz)	18 - 20	kHz (variable)
DC Output Power (into On-Board Charge Module)		
Output Voltage	215	VDC
Output Current	13.8	Amps
Output Voltage Ripple Factor	0.76	%
Operating Temperature after 4.0 hours at 3.0 kW output		
Parking Pad: Max observed surface temperature	51	°C
Vehicle Adapter: Max observed surface temperature	48	°C

[1] Manufacturer's Specifications: http://www.pluglesspower.com/wp/wp-content/uploads/2014/02/Plugless_Tech_Specs.pdf
[2] Test conducted at nominal conditions (3.0 kW output, 100mm coil gap, coils aligned) unless otherwise specified

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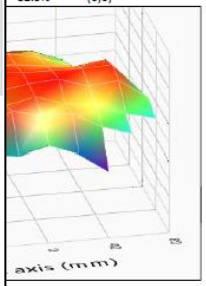

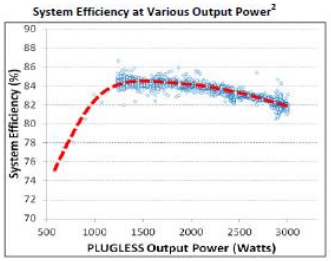

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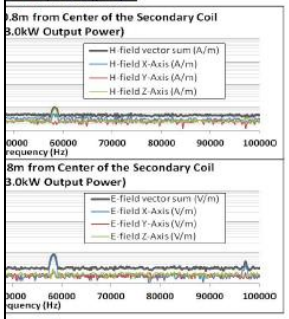

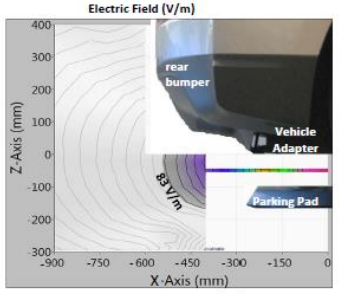

EM Field meter position (X,Z)

1490 A/m (1872 µT)	(0,-50)	centered between coils
5425 V/m	(0,-50)	centered between coils
33.6 A/m (42.2 µT)	(-600,-50)	at rear bumper
57.3 V/m	(-600,-50)	at rear bumper
0.5 A/m (0.6 µT)	(0,250)	inside trunk above charge system
0.8 V/m	(0,250)	inside trunk above charge system

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EM Field measurement position
(0.0 µT) top surface center of parking pad
top surface center of parking pad

EM Field measurement position
(847 µT) top surface center of parking pad
top surface center of parking pad

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http://avt.inl.gov/evse.shtml

Fact Sheet: bench test results (standalone)

Advanced Vehicle Testing Activity — Idaho National Laboratory

PLUGLESS™ Level 2 EV Charging System (3.3 kW) by Evatran Group Inc.

Results from Laboratory Testing off-board the vehicle

Description / Specifications [1]

System Input Voltage operating Voltage	208 to 240 VAC
Circuit Breaker Rating	30 A
Nominal gap between coils	100 mm
Rated maximum power output	3300 watts
Parking Pad (Primary Coil system)	
Shape	Approximately Circular
Size	559 dia. x 470 long mm
Vehicle Adapter (Secondary Coil system)	
Shape	Rectangular
Size	762 long x 457 wide mm

Measured System Parameters during nominal, steady state conditions [2]

Input Power	
Input Voltage	208 VAC
Input Current RMS	28 Amps RMS
Power Factor	0.60
Voltage Total Harmonic Distortion (THD)	3 %
Current Total Harmonic Distortion (THD)	132 %
Wireless Power Transfer Operation	
Operating Frequency (kHz)	18 - 20 kHz (variable)
DC Output Power (into programmable DC electronic load)	
Output Voltage	215 VDC
Output Current	13.9 Amps
Output Voltage Ripple Factor	0.75 %
Operating Temperature	
Parking Pad: Max observed surface temperature	51 °C
Vehicle Adapter: Max observed surface temperature	48 °C

[1] Manufacturer's Specifications: http://www.pluglesspower.com/wp/wp-content/uploads/2014/02/Plugless_Tech_Specs.pdf
[2] Test conducted at nominal conditions (3.0 kW output, 100mm coil gap, coils aligned) unless otherwise specifie

Efficiency

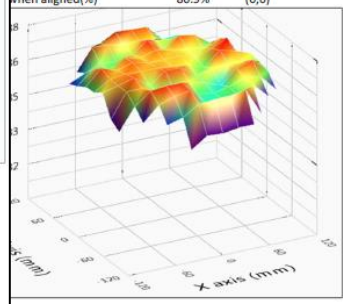
less Charging System Efficiency

iency = Energy out of PLUGLESS™ Vehicle Adapter into programmable DC Load / Energy into PLUGLESS™ Control Panel from 208 VAC

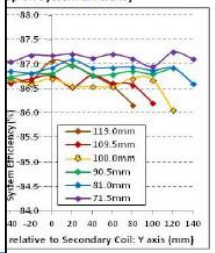
y variation with coil misalignment [2]

Efficiency (%)	87.3%	(80,20)
when aligned(%)	86.9%	(0,0)

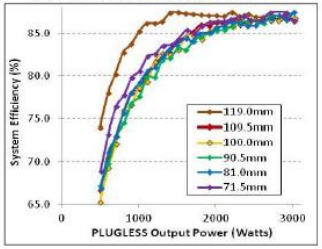
Primary Coil position relative to Secondary Coil (mm)



ap on System Efficiency [2]

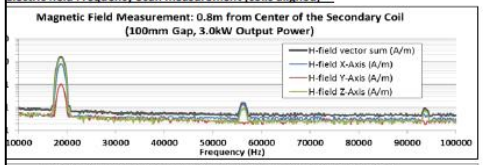


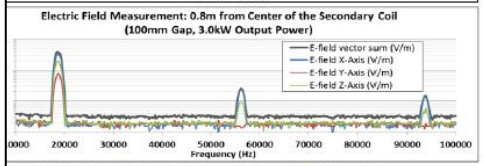
System Efficiency at Various Output Power [2]



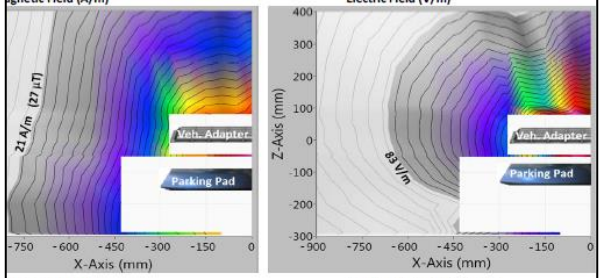
agnetic and Electric Field

Electric field Frequency Scan measurement (coils aligned) [2,3]





agnetic & Electric fields around the rear side of the PLUGLESS system [2]



measurements [2]

aximum measured H-field	1587 A/m (1994 μT)	(0,-50) between coil centers
aximum measured E-field	6833 V/m	(-50,80) above the vehicle adapter
ield 0.6m from coil center	42.7 A/m (53.7 μT)	(-600,-50) at rear of system
ield 0.6m from coil center	101.5 V/m	(-600,-50) at rear of system

EM Field meter position (X,Z)

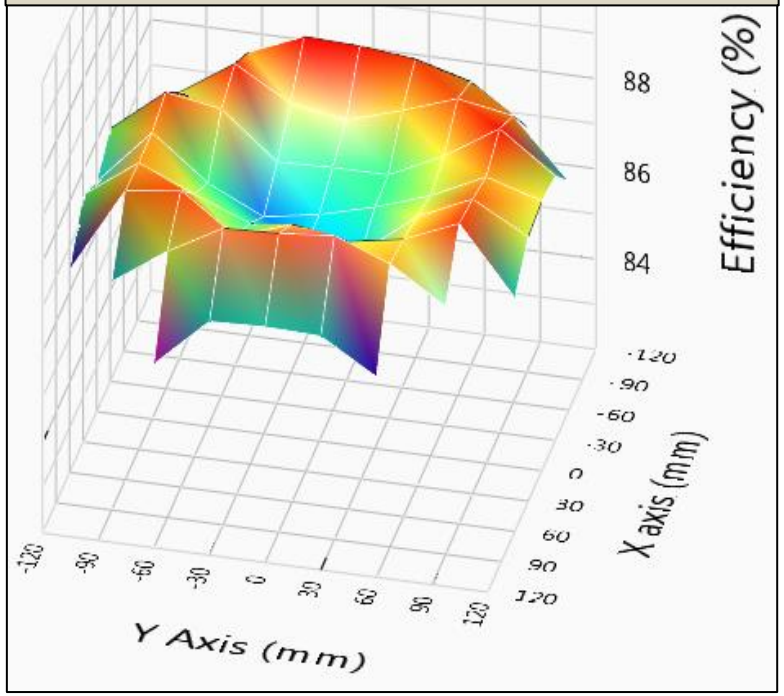
[3] EM field measurement is centered between the gap (50mm below secondary coil) 0.8m from Secondary Coil Center along X-axis

http://avt.inl.gov/evse.shtml

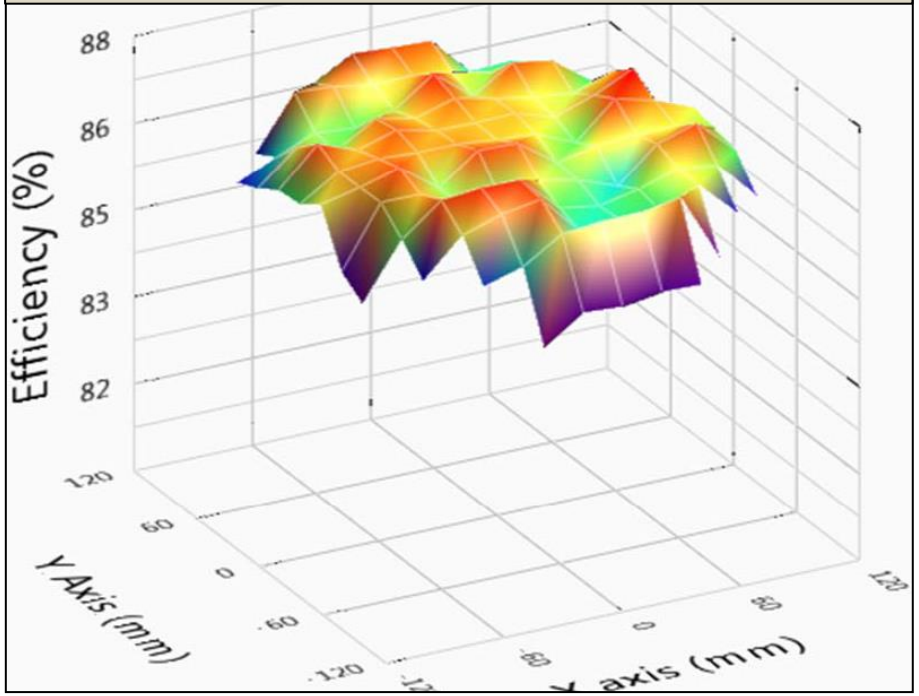
INL data enabled efficiency improvements

- INL's evaluation of the pre-production PLUGLESS system led to:
  - Improvements for the production PLUGLESS, based on INL test results
    - More consistent efficiency across range of misalignment

Pre-production PLUGLESS



Production PLUGLESS



Conductive Charging: Evaluation and Test Procedure Development

Conductive EVSE test procedures for Energy Star

- Draft document created for Level 1 and Level 2 EVSE testing
  - Definitions
  - Test equipment requirements
  - Test procedures
    - Standby power consumption
    - Power consumption during charging
- Recommendations for consideration of additional features that may impact EVSE power consumption
  - EVSE rated maximum current
  - Cord length
  - Additional features:
    - Status lights, communication, touch screen, # of cords, etc.

Evaluation of 4 smart grid capable EVSE

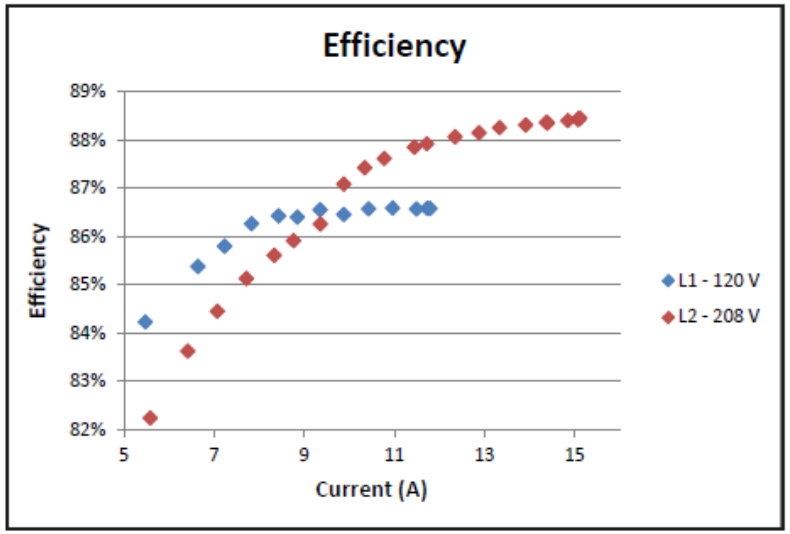
- Four FOA awardees developed EVSE with smart grid communication capabilities
  - GE, Eaton, Delta, Siemens
- Final deliverable EVSE were evaluated by INL
  - Operational and efficiency testing
- Cyber Security Vulnerability assessment
  - Physical security
  - Communications security (wired and wireless)
  - Software and firmware assessment

On-board charger power quality

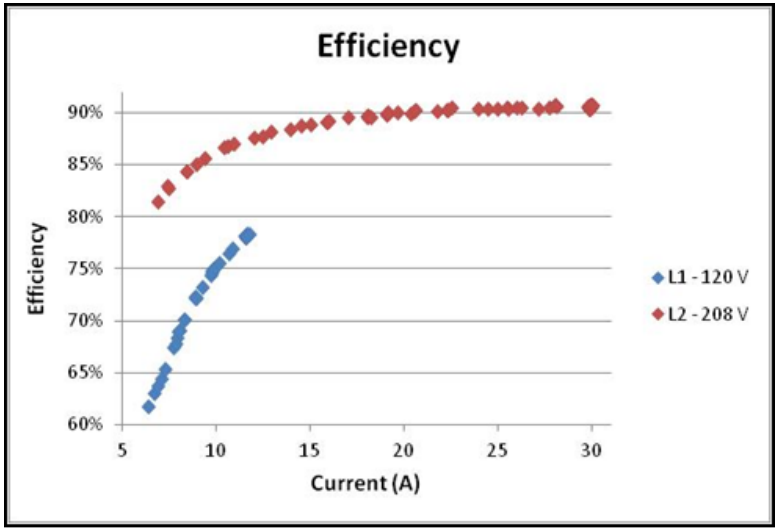
- With smart EVSE, plug-in electric vehicles could be controllable loads
- Vehicle response must be understood for effective use in a smart or micro grid application
  - Every vehicle will respond differently
- INL supports SAE J2894 standard development
- Characterized the on-board charger for two vehicles
  - 2012 Chevrolet Volt (3.3 kW charger)
  - 2015 Nissan Leaf (6.6 kW charger)

Test results: efficiency

2012 Volt

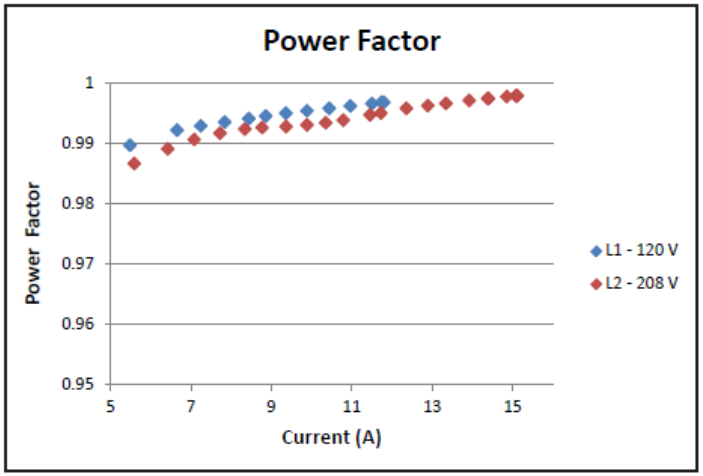


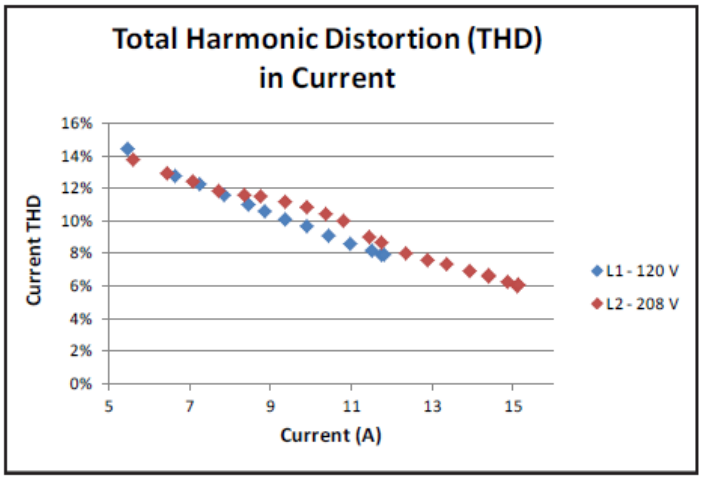
2015 Leaf



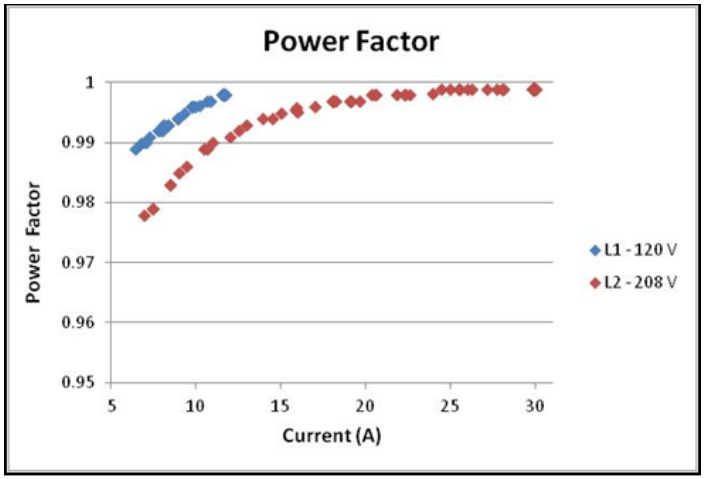
Test results: power quality

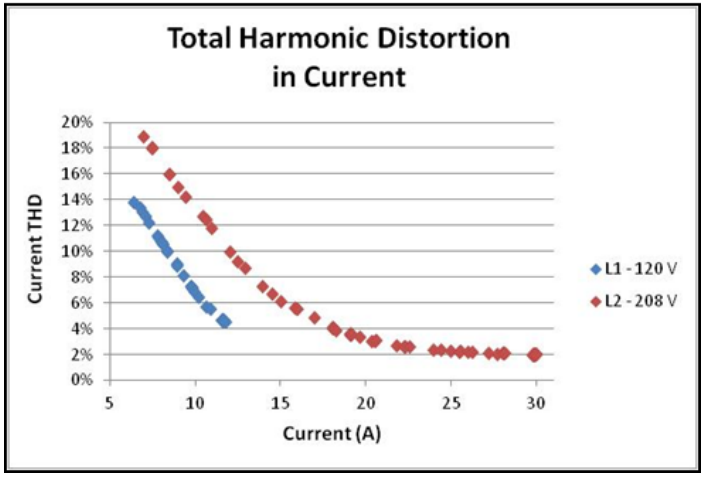
2012 Volt





2015 Leaf

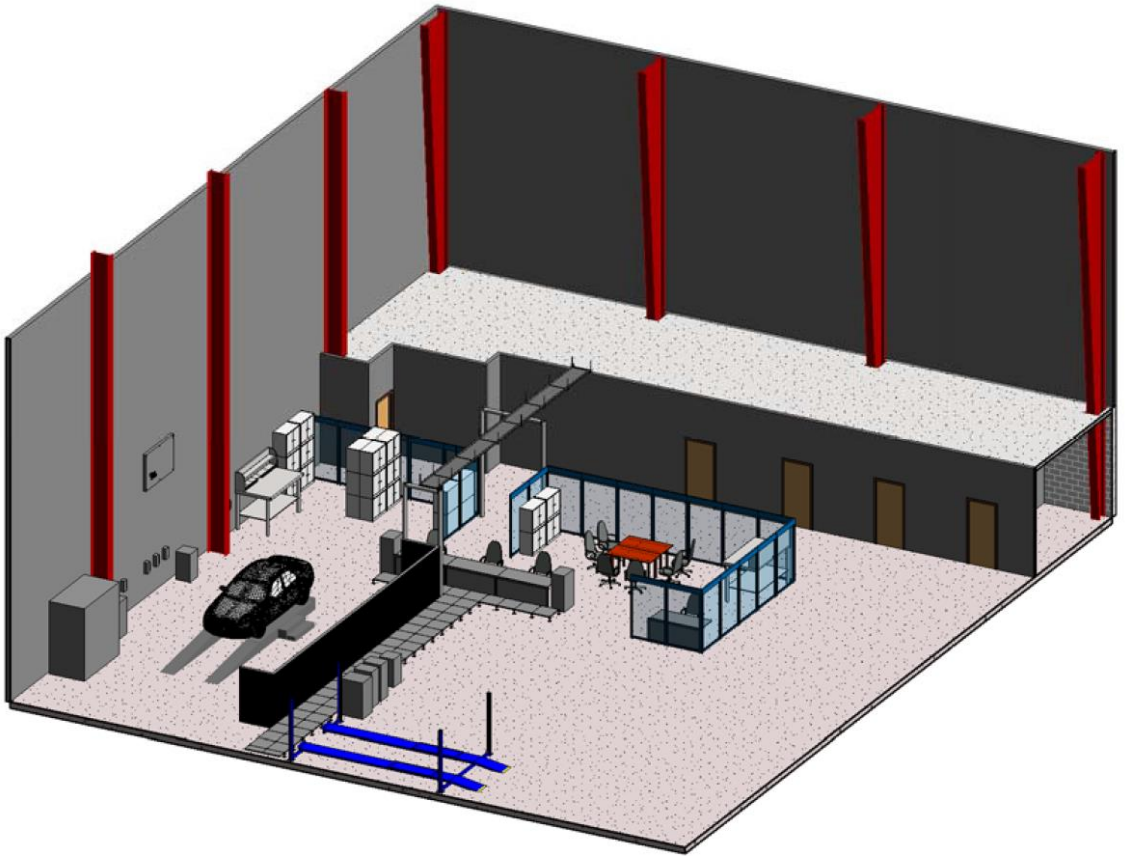




INL's EVI Laboratory: Looking to the Future…

Facility improvements

- Increased workspace
- More grid capability
- Ability to evaluate the interaction of multiple vehicle charging systems simultaneously
- Improved Cyber Security assessment tools and capabilities
- Coordinated testing and evaluation of interaction with INL's Grid Systems RTDS and Micro Grid demonstration facility



Summary

INL's EVI lab is the U.S. DOE core capability for testing and evaluating wireless and conductive charging systems

- Support codes and standards test procedures development
  - SAE J2954, J2894, and EPA Energy Star
- Benchmark advanced technologies
  - Wireless and Conductive charging system efficiency, standby power consumption, and power quality impact to the grid
- Cyber Security vulnerability evaluation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